



## Original Article

# Risk of injury to vascular-nerve bundle after calcaneal fracture: comparison among three techniques



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## ABSTRACT

**Objective:** To ascertain whether the number of screws or pins placed in the calcaneus might increase the risk of injury when three different techniques for treating calcaneal fractures.

**Method:** 126 radiographs of patients who suffered displaced calcaneal fractures were retrospectively analyzed. Three surgical techniques were analyzed on an interobserver basis: 31 radiographs of patients treated using plates that were not specific for the calcaneus, 48 using specific plates and 47 using an external fixator. The risk of injury to the anatomical structures in relation to each Kirschner wire or screw was determined using a graded system in accordance with the Licht classification. The total risk of injury to the anatomical structures through placement of more than one wire/screw was quantified using the additive law of probabilities for the product, for independent events.

**Results:** All of the models presented high explanatory power for the risk evaluated, since the coefficient of determination values ( $R^2$ ) were greater than 98.6 for all the models. Therefore, the set of variables studied explained more than 98.6% of the variations in the risks of injury to arteries, veins or nerves and can be classified as excellent models for prevention of injuries.

**Conclusion:** The risk of injury to arteries, veins or nerves is not defined by the total number of pins/screws. The region and the number of pins/screws in each region define and determine the best distribution of the risk.

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## Risco de lesão do feixe vasculonervoso após fratura do calcâneo: comparação entre três técnicas

### R E S U M O

#### Palavras-chave:

Calcâneo/lesões  
Pinos ortopédicos  
Parafusos ósseos  
Procedimentos cirúrgicos  
operatórios/métodos

**Objetivo:** Verificar se o número de parafusos ou pinos colocados no calcânhar aumentaria o risco de lesão quando usamos três técnicas diferentes para o tratamento das fraturas.

**Método:** Foram analisadas retrospectivamente 126 radiografias de pacientes que sofreram fratura desviada do calcânhar. Foram analisadas três técnicas cirúrgicas sob a forma inter-observador: 31 radiografias de pacientes tratados com placa não específica para o calcânhar, 48 com placa específica e 47 com fixador externo. O risco de lesão das estruturas anatômicas em relação a cada fio de Kirschner ou parafuso foi determinado pelo sistema de graduação segundo a classificação de Licht. A quantificação do risco total de lesão das estruturas anatômicas na colocação de mais de um fio/parafuso foi calculada pela lei aditiva das probabilidades do produto para eventos independentes.

**Resultados:** Todos os modelos apresentaram um alto poder de explicação do risco avaliado, uma vez que os valores do coeficiente de determinação  $R^2$  são maiores do que 98,6 para todos os modelos. Portanto, o conjunto de variáveis estudado explica mais de 98,6% das variações dos riscos de lesão das artérias, veias ou dos nervos e podem ser classificados como excelentes modelos para prevenção de lesões.

**Conclusão:** O risco de lesão das artérias, veias ou dos nervos não é definido pelo total de pinos/parafusos. A região e a quantidade de pinos/parafusos em cada região definem e determinam melhor a distribuição do risco.

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## Introduction

Fractures of the calcaneus account for 60% of the fractures of the tarsus.<sup>1,2</sup> Although calcaneal fractures account for only 1–2% of all fractures in all parts of the skeleton, they are still a major challenge for orthopedists.<sup>2–6</sup> In young patients, they are frequently caused by high-energy trauma. Approximately 75% of these fractures are intra-articular.<sup>4,7,8</sup> Calcaneal fractures present a high rate of unsatisfactory results, with great morbidity for the patients.

The ideal treatment for intra-articular fractures of the calcaneus remains a matter of controversy, despite the advances in imaging diagnostics and surgical techniques.<sup>9</sup> Several surgical techniques for treating displaced intra-articular fractures exist, and these include: open reduction with internal fixation,<sup>5,9</sup> minimally invasive techniques,<sup>10</sup> percutaneous techniques,<sup>11</sup> percutaneous calcaneoplasty<sup>4</sup> and external fixation.<sup>12</sup> Independent of the technique used, various anatomical structures in the medial region of the heel may be at risk of iatrogenic injuries caused by the tips of screws, drill bits, external fixator pins or Kirschner wires.<sup>13–15</sup>

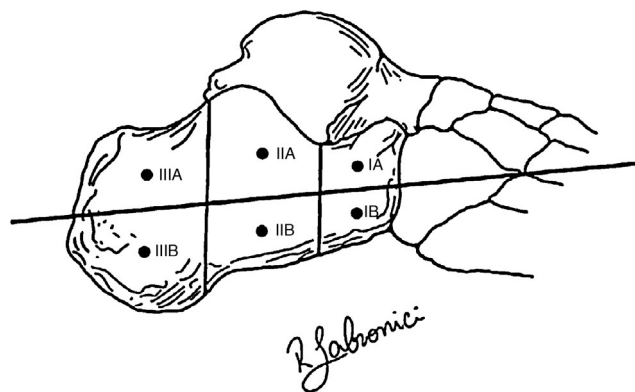
The objective of this study was to investigate whether the number of screws or pins placed in the heel would increase the risk of injury, in using three different techniques for treating calcaneal fractures.

## Material

A retrospective analysis was conducted on 126 radiographs on patients who suffered displaced fractures of the heel

in 2013 and 2014. Cases of fractures without displacement and fractures treated conservatively, and patients for whom no postoperative radiographic control was available, were excluded. Three surgical techniques were analyzed in inter-observer form: 31 radiographs from patients who were treated using a plate that was not specific for the calcaneus, 48 with a specific plate and 47 with an external fixator. These patients were treated at four institutions.

To calculate the risk of injury to nerves, arteries and veins, the heels were divided into six different zones, as illustrated in Fig. 1. Zones IA and IB were located in the anterior tuberosity of the calcaneus, from the calcaneocuboid joint line to a line in the region of Gissane's angle. Zones IIA and IIB were located in the region of the calcaneal body, from the line of Gissane's angle



**Fig. 1 – Diagram showing the six zones of the calcaneus for calculating the risk of injury to nerves, arteries and veins.**

**Table 1 – Likelihood of injury to arteries, veins, nerves and tendons according to the zone of the heel.**

Zone of the heel	Point of comparison			
	Artery	Vein	Nerve	Tendon
IA	0.434	0.434	0.132	0.0
IB	0.208	0.208	0.132	0.0
IIA	0.151	0.170	0.113	0.0
IIB	0.038	0.038	0.038	0.0
IIIA	0.075	0.075	0.057	0.0
IIIB	0.019	0.019	0.019	0.0

Source: data from the hospital service files.

to the end of the posterior tuberosity of the talus. Zones IIIA and IIIB were located in the region of the posterior tuberosity of the calcaneus.

According to Labronici et al.,<sup>15</sup> the probability of injuries to the arteries, veins, nerves and tendons in the six zones studied was based on the classification of Licht et al.<sup>16</sup> for high risk, as shown in Table 1. This study demonstrated that, for example, the likelihood of artery injury upon crossing the medial cortex in zone IA was 0.434 or 43.4%.

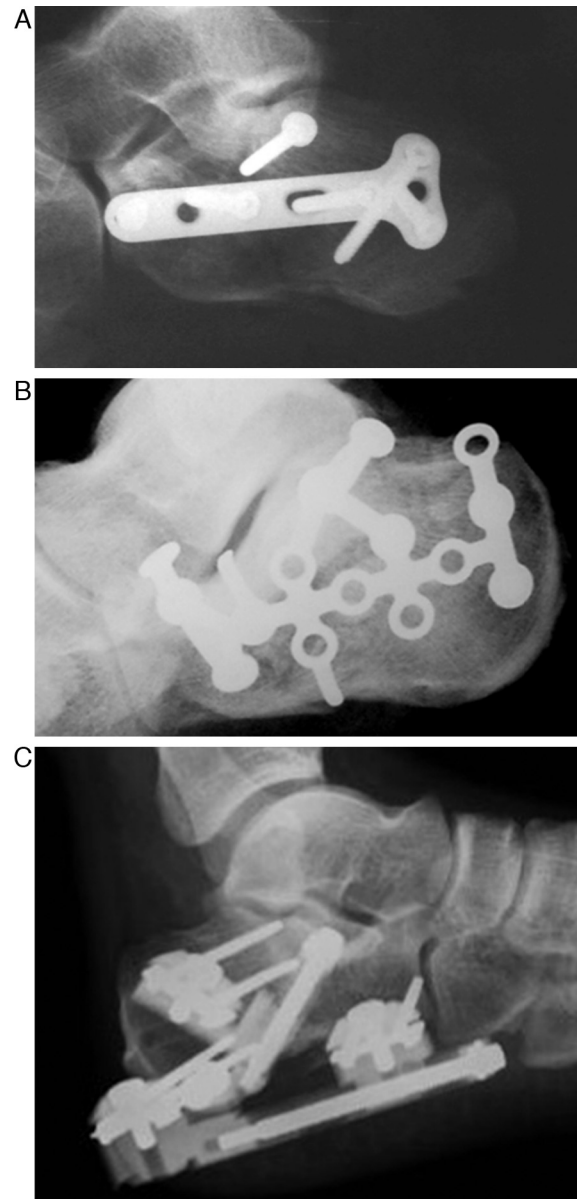
Generalizing, the total likelihood of injury of an anatomical point, in placing  $n$  wires or screws, is the sum of all the individual probabilities (one by one) minus the probabilities of the two-by-two combinations, plus the probabilities of all the three-by-three combinations, minus the probabilities of all the four-by-four combinations, plus the sum of all the five-by-five combinations, and so on, until the  $n$ -by- $n$  combinations are reached.

$$\begin{aligned} & \sum \Pr(F_i) - \sum \Pr(F_i \cap F_j) + \sum \Pr(F_i \cap F_j \cap F_k) \\ & - \sum \Pr(F_i \cap F_j \cap F_k \cap F_l) + \sum \Pr(F_i \cap F_j \cap F_k \cap F_l \cap F_m) \\ & - \Pr(F_1 \cap F_2 \cap F_3 \cap F_4 \cap F_5 \cap F_6) \end{aligned}$$

This was the mathematical formula that was determined for calculating the risk. It was transformed into a computer program and then was analyzed by three researchers independently, in order to measure the three techniques used (Fig. 2).

## Statistical methodology

The data gathered were analyzed through multiple linear regression in the SPSS software (Statistical Package for the Social Sciences), version 22.0. Multiple linear regression analysis is a technique for confirming dependence. Its aim is to examine the behavior of a dependent variable, measured as a function of other explanatory variables. The objective of this study was to evaluate the relationship between the risk of injury to an artery, vein or nerve and the number of screws or pins placed in each region of the calcaneus (A1, A2, A3, B1, B2 or B3). If  $A_i$  is the number of screws or pins placed in region A, index 'i', and  $B_i$  is the number of screws or pins placed in region B, index 'i', the general linear regression model that explains the relationship between the risk of injuring an artery, vein or



**Fig. 2 – (A) Radiograph of a calcaneal fracture treated using a nonspecific plate; (B) radiograph with specific plate; and (C) radiograph with external fixator.**

nerve and the number of screws placed in each region is given by:

$$\text{Risk} = a_1A_1 + a_2A_2 + a_3A_3 + b_1B_1 + b_2B_2 + b_3B_3 + u, \quad (1)$$

where risk is the dependent variable;  $a_i$  and  $b_i$  are the angular coefficients of each respective variable  $A_i$  and  $B_i$ ; and  $u$  is the error term or residual difference between the real risk and the value predicted by the model. This error represents the variables that were not included in the model and may have some power for explaining the risk.

The theoretical model chosen does not have an intercept, since the risk should be null when no screw or pin is placed. All the parameters of model (1) were estimated through the ordinary least squares method. The significance of the parameters

was evaluated using Student's *t* test and the significance of the model was evaluated using the ANOVA *F* test. The assumptions of the model (i.e. normal distribution of the independent variable, absence of heteroscedasticity and absence of multicollinearity) were analyzed using the Kolmogorov-Smirnov test, Glejser test and VIF and tolerance statistics, respectively.

Given that the risks of injuring an artery, vein or nerve are independent, a linear regression model was proposed for each of the risks, for each type of procedure analyzed: placement of nonspecific plates, plates specific for the calcaneus and external fixators. In this manner, nine regression models were obtained. In addition to the analysis on the multiple linear regression model, a simple regression model between the risk and the total number of pins (*T*) placed was analyzed, given by:

$$\text{Risk} = aT + e, \quad (2)$$

where *a* is the angular coefficient of the variable to be estimated and *e* is the error term.

Despite the recommendation to use beta regression for the risk variable, since this is a variable of limited interval [0,1], simple linear regression was chosen because this had the advantages that the results could be easily interpreted, the sample size ensured non-violation of normality for the variables and none of the models proposed violated the assumptions of the multiple linear regression model (absence of heteroscedasticity and absence of multicollinearity). In addition, the models were evaluated by means of beta regression, which confirmed the significance of all the variables proposed, in all the models.

## Results

Table 2 demonstrates the *p*-values of the Kolmogorov-Smirnov test. This test was used to assess whether each of the

**Table 2 – *p*-Values of the Kolmogorov-Smirnov test for the variables of risk of injury to arteries, veins or nerves, in the three procedures involved, i.e. placement of nonspecific plates, plates that are specific for the calcaneus and external fixators.**

Procedure	Risk of injury to arteries	Risk of injury to veins	Risk of injury to nerves
Non-specific plates	0.103	0.108	0.595
Plates specific for calcaneus	0.134	0.116	0.195
External fixators	0.070	0.062	0.639

dependent risk variables presented normal distribution, for each type of procedure analyzed: placement of nonspecific plates, plates specific for the calcaneus and external fixators. It was observed that none of the *p*-values greater than 5% led to rejection of the null hypothesis of normality, which was the desired situation.

In addition to the test for normal distribution, the Glejser test and the VIF and tolerance statistics also provided the assurance that heteroscedasticity and multicollinearity were absent from all the models proposed.

Table 3 demonstrates the estimates for the coefficients of each proposed model, described as defined in Eq. (1). For the nine models proposed, the overall statistical significance of the model was confirmed (*p*-value of the ANOVA *F* test < 0.001), along with the significance of all of the variables (numbers of pins and screws in each area), separately (*p*-value of Student's *t* test < 0.001). All the models presented high explanatory power for the risk evaluated, given that the values of the coefficient of determination *R*<sup>2</sup> were greater than 98.6 for all the models. Therefore, the variables studied explained more than 98.6% of the variation of the risks of injury to the arteries, veins or nerves, and can be classified as excellent models for injury prevention. In comparing the adjusted values for the coefficient

**Table 3 – Estimates of the coefficients of the linear regression models and coefficient of determination of the model (*R*<sup>2</sup>).**

Coefficients	Procedure								
	Straight plates			Plates for calcaneus			External fixators		
	Risk to artery	Risk to vein	Risk to nerve	Risk to artery	Risk to vein	Risk to nerve	Risk to artery	Risk to vein	Risk to nerve
A1	20.5	20.3	9.4	18.2	18.0	8.8	27.9	27.8	10.8
A2	11.7	12.3	8.8	8.5	9.0	7.5	10.6	11.6	9.0
A3	6.6	6.6	4.9	5.8	5.8	4.2	7.4	7.4	5.1
B1	8.8	8.7	8.1	10.9	10.9	9.0	13.9	13.8	10.6
B2	6.9	7.0	4.5	5.6	5.7	3.9	5.0	5.0	3.7
B3	5.5	5.6	3.0	4.2	4.2	2.5	4.2	4.3	2.4
<i>R</i> <sup>2</sup> of model (1)	98.88	98.85	99.60	98.71	98.68	99.56	98.72	98.69	99.69
Adjusted <i>R</i> <sup>2</sup> of model (1)	98.81	98.77	99.58	98.65	98.65	99.54	98.63	98.61	99.67
Correlation between total number of pins and risk	0.68	0.68	0.63	0.60	0.61	0.82	0.59	0.60	0.82
<i>R</i> <sup>2</sup> of model (2) involving total number of pins and risk	0.46	0.46	0.40	0.36	0.37	0.67	0.35	0.36	0.67



of determination  $R^2$ , it was observed that the models for predicting the risk of nerve injury were best, since they explained approximately 100% of the risk.

On the last two lines of Table 3, the correlation and coefficients of determination  $R^2$  of the model proposed by Eq. (2) are also analyzed. In this, the risk is only considered as a function of the total number of pins and screws. It was observed that the models thus proposed presented low explanatory power for the risk. Thus, these models have not been displayed. The risk of injury to arteries, veins or nerves was not defined by the total number of pins or screws. The region and the number of pins or screws in each region explained and determined the distribution of risk better.

## Discussion

For each procedure (nonspecific plates, plates specific for the calcaneus and external fixators), this study used statistical multiple linear regression models that efficiently estimated the risk of injury to arteries, veins and nerves from the number of pins or screws that each procedure in each region would use. To judge which procedure is least invasive, the number of pins or screws to be placed in each procedure in each region needs to be planned and the expected value for the respective risk should be calculated from the equations obtained. The coefficients thus estimated showed that the pins and screws in the region A1 were the ones that contributed most toward increasing the risk of injury to the arteries, veins or nerves. Pins or screws in the regions A2 and B1 also contributed toward the risks of injury.

Meticulous knowledge of the anatomy of the hindfoot is an important prerequisite for planning for placement of pins or for open reduction and internal fixation of heel fractures. Structures contained within the tarsal tunnel, which are close to the medial region of the calcaneus, are vulnerable to injury caused by pins, drill bits or screws that penetrate the medial cortex of the calcaneus.<sup>15</sup> Albert et al.<sup>17</sup> divided the calcaneus into three zones. Zone I starts at the calcaneocuboid joint and extends posteriorly as far as Gisane's critical angle; zone II starts at Gisane's angle and extends posteriorly to include all of the posterior facet; and zone III encompasses the posterior tuberosity. The risk of injury to the structures of the medial region was calculated for each location into which pins were inserted in the lateral region. They concluded that pins placed in the subchondral bone of the posterior facet or anterior to Gisane's critical angle might increase the risk of injury to the medial structures of the calcaneus. Labronici et al.<sup>15</sup> demonstrated that division into six zones was more reproducible, with their respective risks of injury to the anatomical structures. The risk of injury can be quantified through the law of addition of probabilities, and this allows better planning with regard to the sites of lower risk for pin placement. However, it is important to emphasize the difficulty involved in predicting the likelihood of neurovascular injury caused by anatomical variations that are encountered in the tarsal canal, with subdivision of the tibial nerve into its medial plantar, lateral and medial calcaneal branches.

Some authors<sup>18-21</sup> observed that the injuries most frequently affecting cutaneous nerves were to the sural nerve

laterally and the tibial nerve posteromedially. These injuries usually result in hypoesthesia and are treated conservatively, except if a neuroma develops, which should then be treated surgically.

## Conclusion

Through comparing the risk estimates obtained, surgeons can evaluate which procedure would be safest, so as to avoid the risk of injury to arteries, veins or nerves.

The coefficients estimated through this study showed that pins and screws in the region A1 were the ones that contributed most toward increasing the risk of injury to the arteries, veins or nerves. Pins or screws in the regions A2 and B1 also contributed toward the risk of injury.

The risk of injury to the arteries, veins and nerves is not defined by the total number of pins and screws. The region and the number of pins and screws in each region explain and determine the distribution of the risk.

## Conflicts of interest

The authors declare no conflicts of interest.

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